DESCRIPTION AND EVALUATION OF FISH PASSABLE DIVERSION STRUCTURES

for

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PURPOSE

The U.S. Fish and Wildlife Service (FWS), Oregon Fish and Wildlife Office, requested an evaluation of fish passable diversion structures describing the state of the state for diversion structures in Oregon. FWS sought updated information to guide planners and decisions makers that are selecting diversion structures as they implement FWS Restoration Programs. The selection process presented is a screening level tool for initial planning and cost estimating. A range of diversion structures are described and then evaluated with respect to the following characteristics:

- Unit cost per diverted flow
- Applicability of structure for various stream sizes and types
- Range of applicable flows
- Effects and impacts on bed load transport
- Effects on temperature and fine sediment
- Ability to pass fish
- Maintenance and operation requirements
- Difficulty of engineering design
- Construction difficulty

BACKGROUND

The primary purpose of an irrigation diversion structure is to deliver irrigation water from a stream to the irrigation delivery system. Typical irrigation delivery systems deliver water at a flat grade (typically 0.1 to 0.3 percent) to the first point of use. Installing the diversion structures at the lowest elevation possible minimizes the length of the delivery system. For irrigators, the selection of a diversion structure is primarily based on the performance of the structure to deliver water, construction complexity, and cost and maintenance.

Historically, diversion structures have been constructed of hay bales, gravel dams, fence posts, fence netting, concrete, steel, wood and nearly anything else that impedes water flow enough to divert water into a delivery system. Other qualities such as fish passage, sediment transport, or aesthetics were often not considered important by irrigators unless these features altered the delivery of irrigation water. Some structures were designed with removable or permanent weirs to raise the water surface. These structures rarely incorporated fish passage. In addition, many streams have incised since diversion structures were installed. Fish passage has been reduced or eliminated by the combination of these two factors.

FISH PASSAGE

Oregon water law required fish passable diversion structures even prior to Oregon's statehood. Recently, House Bill 3002 combined several pieces of legislation giving the Oregon Department of Fish and Wildlife the flexibility to cost share fish passage and to grant specific waivers for fish passage requirements. Listing of chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), steelhead (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus*) as threatened or endangered species greatly accelerated efforts to improve fish passage past diversion structures.

DIVERSION STRUCTURES

A range of diversion structures has been used in Oregon (Appendices 2 and 3). Fish passable gravity diversions meeting Oregon State Law generally consist of the following components:

- An instream permanent weir or an adjustable, temporary weir. In some cases, flow depths are sufficient to provide water without any instream barrier (weir).
- A water control device. Often a headgate is installed to control the flow of water into a ditch or pipeline. An example of a small headgate is included in Appendix 2 (Photo 1).
- An approved fish-screening device. Fish screens generally consist of a physical barrier to fish movement (a perforated plate or slotted plate) sized to exclude juvenile fish (current ODFW opening size standard is 0.09 inches), a cleaning device and a bypass to safely transport fish back to the stream channel.
- A standard measuring device including:
    - Weirs
    - Flumes
    - Propeller meters
    - Magnetic and ultrasonic flow meters

The Bureau of Reclamation Water Measurement Manual (1997) includes a thorough discussion of these devices.

The diversion structures discussed in this paper include:

- Permanent Weir Diversions
    - Rock or boulder weirs, cross-vanes, ramp weirs
    - Steel
    - Log
    - Concrete
- Temporary Weir Diversions
    - Overshot weir gates
    - Headgates (radial gates, slide gates)
    - Stop log including lay-flat stanchions
    - Air bladders
- Pump Stations
    - Submersible pump
    - Turbine pump
    - Centrifugal pump
- Stream Bed Diversions
    - Infiltration galleries
    - Vortex tubes

Push-up gravel dikes and earthen berms are used for diversion structures across the west. The US Army Corps of Engineers and Oregon Division of State Lands fill and removal permits are required for legal push-up irrigation diversions. Because little engineering is required, and these structures don't pass fish well, they are not discussed in this paper.

Several terms are used in the agricultural and irrigation engineering community that may be unfamiliar to others. Appendix 4 is a glossary of irrigation terms from The Irrigation Association. Following are several terms used frequently in this paper:

- <u>Stop log</u> – a wooden, plastic or metal "board" used to raise the elevation of a weir structure. Wooden stop logs are most common and are generally two to four inches thick and four to twelve inches tall. The stop logs must be supported at both ends. Stop logs are commonly used in lay-flat stanchion diversions and as water surface elevation control in fish screens and in-ditch structures.
- <u>Check</u> – this term is often used interchangeably with "weir". A "check" raises the water surface by forcing the water to go over the top – the same as a weir.
- <u>Headgates</u> -- headgates are generally moveable metal or wooden plates used to control the flow of water. The plate or "gate" is usually moved by a threaded rod or screw and is continuously adjustable. Alternatively, chains, jacks and other means are used to open and hold a gate in a steady position.
- <u>Lay-flat stanchion</u> – these structures are used to retain stop logs and raise the water surface elevation upstream of the stanchion. Generally fabricated of welded steel, the stanchions "lay-flat" when not in use. Removal of bolts, or repositioning of support elements allows the stanchion to be removed or dropped to the invert of the channel.

- Air bladders – these structures are fabricated from tough, resilient rubber or other fabrics in a long narrow shape. The bladder is inflated with air supplied from an on-site air compressor.
- Rock weirs, cross vanes, ramp weirs and boulder weirs -- these structures are intended to raise the water surface of a stream or river. Forcing stream flow over and between rocks and boulders restricts the flow and elevates the water surface.
- Overshot weir gate -- this structure raises the instream water surface by tilting a steel plate around a hinge. Water flows over the plate, and the change of water surface elevation is controlled by a gate lift (cables, chains or hoists).
- Permanent stop log post – posts are attached to a foundation and provide a place for insertion of stop logs. The posts are fabricated of concrete, wood and steel and must have a slot or lip for stop logs to rest against.

Permanent Weir Diversions

Permanent weir diversions are generally constructed of rock or concrete. The elevation of the weir cannot be changed without extensive modification to the structure. Weirs must be constructed with effective energy dissipation downstream (e.g., backwatered or with rocks). A typical problem is that the structures may be of a different width than the stream channel. Sedimentation upstream can cause clean water scour downstream. Structures that are too narrow can cause increased velocities with additional scour downstream. These structures should be designed with respect to downstream backwater at a range of flows to ensure fish passage.

Rock weirs can be difficult to site in order to maximize effect while minimizing costs. Hydraulic analyses (i.e., backwater curves) are generally necessary for design. In addition, sealing rock weirs to ensure water flows over the weir can be difficult. Often additional gravels and fines must be placed upstream to seal the structures. Sediment passage must be addressed; the structure must be placed where excess deposition will occur. Shaping of the weir with gaps, or a low center can improve sediment passage.

Log, concrete and steel weirs are all very similar in function if not appearance. These three types of weirs are designed to be nearly watertight and raise the water surface over the top. Sediment passage must be addressed by providing sediment passage notches or an opening blocked by stop logs. Hydraulic analyses (i.e., backwater curves) are generally necessary for design of the structure and to provide fish passage at a variety of flows.

Advantages:
- Inexpensive
- Low maintenance if correctly designed and constructed.

Disadvantages:
- Difficult to modify.
- Scour.

Temporary Weir Diversions

Temporary weir diversions are generally constructed using metal or wooden mechanisms that can be moved fairly easily either by hand or with equipment to change the elevation of the weir. Temporary weirs have an advantage over permanent weirs because the structure can be controlled to meet the required conditions. The height of the weir can be adjusted to provide the water surface elevation required for flow demands.

Lay-flat stanchions provide the benefits necessary for a fish and sediment passable diversion structure. However, these benefits are only provided when the irrigator is willing and able to enter the stream and place or remove stop logs. At times the stream velocities are too high to safely enter the stream, the irrigators are busy with ranch work, or it may be very cold when it is necessary to perform the work. Permanent weirs with lay-flat stanchions or stop log slots can provide some of the same functions as a cross-channel structure with lay-flat stanchions.

Advantages:
- Variable height allows good water level control.
- Does not impede flow during non-irrigation periods.

Disadvantages:
- Maintenance.

Pump Stations

A pump station does not alter or place a barrier in the stream to divert flow but pumps water from the stream to the irrigation system. Pumps have several advantages and disadvantages over weir style diversion structures.

Advantages:
- Access for maintenance
- Lower initial cost
- Much less instream work necessary
- Inexpensive fish screens available
- No fish barriers

Disadvantages:
- Difficulty in concentrating the water at low flows to submerge the pump intake
- Sediment fills the pump sump
- Difficulty protecting pump intake during icing and high water events
- Continued operation and maintenance costs

Stream Bed Diversions

Other diversion structures include infiltration galleries and vortex tubes. These structures work by diverting down through screens and constructed facilities to the irrigation system. These structures are generally more complex to design and expensive to build but provide the advantages of improved fish passage and low maintenance. These structures do not inhibit fish passage because no structures protrude above the streambed.

Advantages:

- Excellent fish passage.

Disadvantages:

- Expensive.
- Difficult to design and construct.

CHARACTERISTICS AND SELECTION PROCESS

The characteristics used to evaluate fish passable diversion structures were developed based on criteria identified as important for fish, the design of previous structures, and FWS experience. A decision matrix was developed to rate the characteristics of the identified diversion structures.

The decision matrix is an interactive spreadsheet. An example is shown in Table 1. For the approximate location of the diversion the user needs to estimate the following:

- Width (feet)
- Height (feet)
- Bank height from the stream bed (feet)
- Flow diverted (cfs)

These values are entered at the top of the spreadsheet. Some structures are useful for a limited range of flows. Those structures that cannot handle the anticipated flows should be eliminated from contention. Some structures are useful for a limited range of widths. Those structures that are not within the range of the expected channel width should be eliminated from consideration. Important characteristics of the proposed structure should be identified and the compared to the grades shown in Table 1. For example, if the ability to pass bed load and low operation and maintenance are important, then those structures with low grades should not be considered.

Each of these structures can be designed to pass bedload and to provide excellent fish passage. Some of the concerns with these issues can be addressed with careful and thoughtful design and attention to the sediment transport and channel forming processes. For example a rock weir can be designed to provide for sediment passage by providing either a low flow sediment passage notch or by spacing the header rocks on a weir to allow sediment to flow through. Concrete, steel and log weirs can be designed with slots for sediment transport as well. The problems associated with adjusting a stop log style structure during high flow events can be addressed by providing safe access to a gate or adjustable weir.

The next step is to estimate unit costs. The volumes of materials shown should be reviewed and revised as necessary if the project dimensions are significantly different than those shown in the example. The costs used are shown in Table 2. These should also be reviewed and modified if there are significant differences from the example.

From the list of diversion structures remaining, and the estimated unit costs, an appropriate diversion structure may be selected. Examples of the diversion structures in Oregon are listed in Table 1.

CONCLUSIONS

Each of the diversion structures presented has advantages and disadvantages. Each structure or irrigation withdrawal method must be evaluated for specific site conditions. Unit costs for cross-channel weirs increase very rapidly as channel width increases and/or irrigation withdrawal decreases. Pump systems appear to be very economical at small diversion flows and on larger streams and rivers.

Cost of operation will continue to be a very important factor in choosing diversion methods. On the other hand, the option to install a pump to alleviate the need for semi-annual maintenance associated with stop logs or push-up diversions may be best for small ditches. Impacts to the function of the stream may drive the decision toward a temporary weir style of diversion structure or to a pump to prevent flooding, bank erosion or sedimentation. High weirs are the most prone to these problems.

A method to select fish passable diversion structures was presented as a screening level tool to identify appropriate structures. The method uses a range of characteristics including applicability, important objectives, and estimated unit costs. FWS planners can quickly eliminate potential structures for given scenarios to a short list of structures for further investigation and planning.

Many steps are important in the selection, planning, design and construction of irrigation diversion structures – especially for structures that are intended to safely pass fish. Budget problems for planning, design and construction management are typical as the agencies that historically provided this assistance for smaller structures face increasing demands on their time. An estimate of the time required for to complete a diversion structure project is shown in Table 3.

Table 1. Diversion Structure Decision Matrix

Costs are estimated based on the following dimensions:

Width [ft] (for weirs)	20
Height [ft] (for weirs)	1
Bank Height [ft]	8
Flow diverted [cfs]	2

Note: Footnotes on next page

							Construction Difficulty			Unit Volumes							Costs		Description and Examples		
Range of instream flows	Stream Size - Width	Ability to pass bed load (A - good)	Water Quality (A -not impacted by poor water quality, no concerns)	Fish Passage (A - good fish passage - no design concerns)	Operation and Maintenance (A - low maintenance, no design concerns)	Engineering design difficulty (A -most simple design)	Level of experience (A - Simple Construction)	Type of equip[7]	Time (Length of Construction)	Rock Volume	Excavation Volume	Concrete Volume	Steel Area	Log Volume	Ends Cost	Weir Cost	Unit Cost (structure width)	Unit Cost (flow)	Diversion Type	Example Structure	Project Location
(cfs)	(feet)	(grade)	(grade)	(grade)	(grade)	(grade)	(grade)	(desc)	(grade)	(cy/ft)	(cy/ft)	(cy/ft)	(sq ft/ft)	(cu ft/ft)	($/ft)	($/ft)	($/ft)	($/cfs)		(river)	(county)
50-2500	< 100	B[1]	A[2]	B[3]	A[4]	A[5]	A[6]	exc.	A[8]	1.4	1				250		334	3400	Rock weir	Crooked	Crook
50-2500	< 100	C[1]	A[2]	B[3]	B[4]	B[5]	A[6]	exc.	A[8]	3.5	2.33				500		711	7200	Rock weir		
50-2500	< 100	C[1]	A[2]	B[3]	B[4]	B[5]	A[6]	exc.	A[8]	6.3	3.83				750		1125	11300	Rock weir	Catherine	Union,
1000-5000	All	C[1]	A[2]	B[3]	A[4]	B[5]	B[6]	exc., dewater	B[8]	1.4	6.5	0.7			672		1337	13400	Concrete weir	Catherine Creek	Union
1000-5000	All	C[1]	A[2]	B[3]	A[4]	B[5]	B[6]	exc., dewater	B[8]	1.4	1.0		5		288		492	5000	Steel weir	John Day River	Grant
5-1000	All	C[1]	A[2]	B[3]	A[4]	B[5]	A[6]	exc., dewater	B[8]		1			7.5	250		400	4000	Log weir	Lostine River	Wallowa
5 - 5000	All	A[1]	A[2]	A - C[3]	C[4]	B[5]	B[6]	exc., dewater	B[8]	1.4	1	0.7			288	38	929	9300	Lay flat stanchion	Lostine and John Day	Wallowa and Grant
All	All	A[1]	A[2]	A - C[3]	B[4]	C[5]	C[6]	exc., dewater	C[8]	1.4	1	0.7			288	550	1134	11400	Air bladder	Ochoco Creek	Crook
All	All	A[1]	A[2]	A - C[3]	A[4]	C[5]	C[6]	exc., dewater	B[8]	1.4	1	0.7			288	550	1134	11400	Ramp weir		
All	All	A[1]	B[2]	A[3]	B[4]	C[5]	C[6]	exc., dewater	A[8]						2500	2311	6311	3200	Pump	Grande Ronde	
All	All	A[1]	C[2]	A[3]	D[4]	D[5]	B[6]	exc., dewater	B[8]									17900	Infiltration gallery	Sucker Creek	Josephine

Table 1. Diversion Structure Decision Matrix Footnotes

FOOTNOTES

1. The basic ability of the structure to pass bed load is evaluated here. Any of these structures can and have been designed and operated in a way that prevented bedload movement. Structures that widen the channel, reduce velocities or increase erosion potential tend to reduce bedload movement. The temporary weir structures - including the lay-flat stanchions, air bladder structures and the ramp weirs all have the potential to move bedload very efficiently. However, if the weir is not lowered during sediment movement the structures will function as permanent weir structures.

2. Water quality does not effect the function of the structures rated A or B to any substantial amount. Those rated C are effected to a substantial degree. Specifically the infiltration gallery is effected by the growth of algae in warmer water and by the deposition of fine sediments where turbidity is a problem. The structures may effect the water quality (primarily as effected by temperature) if the structure raises the water surface - increasing the time for solar absorption.

3. Structures are rated for their potential fish passage problems and intrinsic impact to fish. Infiltration galleries that are functioning properly have very little impact to fish (nearly none). Rock weirs were rated lower because the weirs have more tendency to leak and present a barrier. Properly installed weirs may be adapted to changing stream conditions and allow more flexibility in a dynamic situation. Pumps have little impact on fish passage when designed to meet criteria (not considering stream dewatering).

4. Rock weirs have a varied O&M rating because of the difference in maintenance required with higher water surface weirs. lay-flat stoplog structures require at least semi-annual maintenance in-stream - in smaller streams this does not raise many issues. Infiltration galleries are rated very low because of the poor track record in Oregon and Washington. Some groups have been very successful in installing galleries, other structures require replacement of the granular material over the intake pipes after several years. The other concrete, steel and log weirs do not require annual maintenance or much input for operation. The temporary weirs (other than stop log structures) require the use of a air compressors or winches to raise and lower the temporary weir.

5. Rock weir engineering design difficulty is rated as the easiest to design because the structures are fit together in the field, the tolerances are in the range of 0.5 feet and because the structures do not need significant water control to build. The permanent weir structures have no mechanical aspects, the tolerances may be 0.2 feet, however construction of these structures will require significant water control. The rest of the structures have significant mechanical components, and construction of these structures will require significant water control. The infiltration galleries require an in depth investigation into the hydraulic characteristics of the local shallow ground water aquifer.

6. Construction difficulty parallels the engineering difficulty with the exception of the infiltration gallery and log weirs. Infiltration galleries are reasonably simple to build while still requiring significant water control. Log weirs require water control, however the components can be fit and shaped much more easily than sheet pile or poured concrete walls. Pumps must be installed by someone with experience because of the sensitivity of pump performance to installation details.

7. While diversion structures in small stream can be fabricated and installed with backhoes - or even by hand - the typical diversion structure is installed with an excavator or track hoe. Access to the site, control of placement and hoe lifting capacity are typical reasons.

8. Installation time parallels construction and design difficulty with an exception - pumps. An experienced contractor can install a pump relatively quickly depending upon the instream work required to provide a sump for the pump.

Table 2. Diversion Struture Cost Inputs

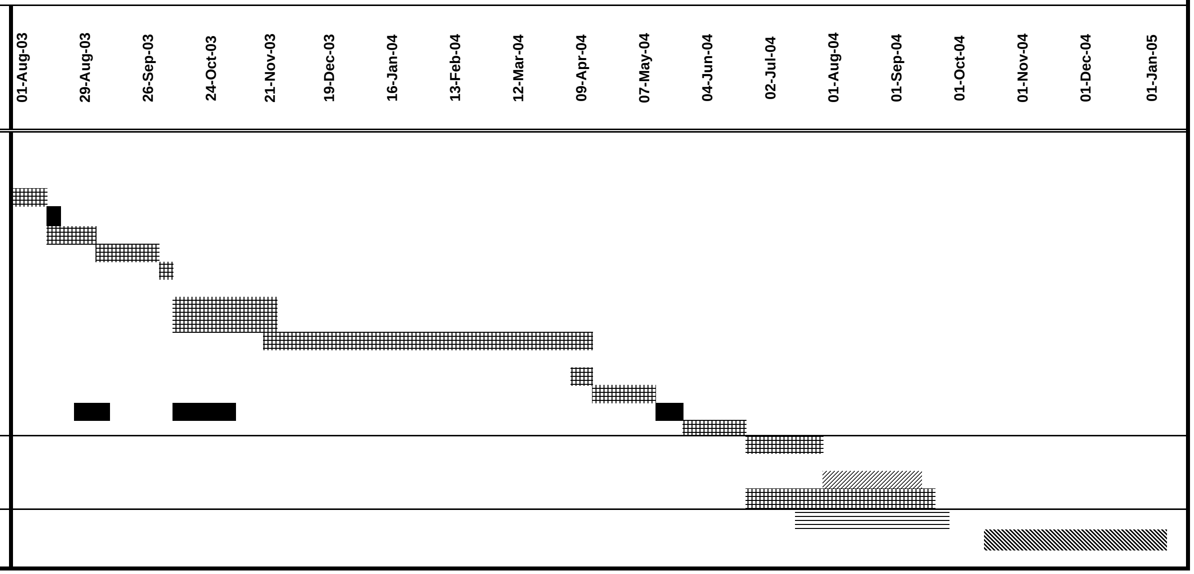
Table 2 - Assumptions

		Initial Cost	Unit Cost	Units
1	Unit Rock Cost		50	$/cy
2	Unit Reinforced Concrete Cost		750	$/cy
3	Unit Fabricated Steel Cost		4	$/lb
4	Unit Bladder Cost		200	$/ft
5	Centrifugal Irrigation Pump Cost	2000	120	$/hp
6	Turbine and Submersible Pump	4300	250	$/hp
7	Dewatering Pump		2000	$/day
8	Mid Size Excavator (50,000 lb)		100	$/hr
9	Dump Truck (10 cy)		100	$/hr
10	Front End Loader (2 cy)		100	$/hr
11	Dozer (D5 Eq.)		100	$/hr
12	Mobilization		10%	of job
13	Pipe Installation (Gravel Road/Tough Digging)		10	$/ft
14	Pipe Installation (Fields/ Moderate Digging)		5	$/ft
15	Unit Instream Excavation Cost		15	$/cy
16	Rock Volume per Foot$_{1\ Foot}$		1.4	cy/ft
17	Rock Volume per Foot$_{2\ Feet}$		2.1	cy/ft
18	Rock Volume per Foot$_{3\ Feet}$		2.8	cy/ft
19	Rock Volume per Foot$_{4\ Feet}$		3.4	cy/ft
20	Excavation Volume for Conc Structure		6.5	cy/ft
21	Conc Volume for Conc Structure		0.67	cy/ft
22	Unit Sheet Pile Cost		20	$/sq ft
23	Unit Log Cost		18	$/cf
24	Inflatable Air Bladder		250	$/sq ft
25	5 hp air Compressor		$6,000	each
26	Manual Controls - Air Bladder, Pump		$ 1,500.00	each
27	Automated Controls - Air Bladder, Pump		$ 11,000.00	each

Table 3. Diversion Structure Planning and Design

Project Schedule

Tasks	Time (days)
Planning	
Landowner Contacts and agency contacts	1
Site Visit	1
Preliminary Water Rights Investigation	3
Feasibility Survey and Design	7
Funding Application	2
NEPA	
Preparation of Environmental and Biological Assessment, Fill and Removal Permit	15
Review and Negotiation w/ Agencies	15
Design	
Design Survey	3
Preliminary Design	15
Landowner Review	1
Plans, Specifications and Estimate Preparation	10 to 60
Construction	
Contractor Selection Process	4
Construction	
Construction Management	51
Instream Work Window	
Vegetative Planting Window	



Planning and Design
Landowner Input
Contractor
Instream Work Window
Vegetative Planting Window

APPENDIX 1
Additional Sources of Information

Water Rights and Measurement
http://www.usbr.gov/research/activity/1998-2000/wr/1998/WR9814.htm
http://www.usbr.gov/research/activity/1998-2000/wr/1999/wr9924.pdf
http://www.usbr.gov/research/activity/1998-2000/wr/1999/wr9927.pdf
http://www.usbr.gov/research/activity/1998-2000/abstracts/wr00.12.pdf
http://www.wrd.state.or.us/publication/aquabook00/index.shtml
http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/
http://www.usbr.gov/wrrl/fmt/wmm/index.htm

Irrigation Terms

http://www.utahia.org/docs/Glossary_Of_Terms.pdf
http://www.irrigation.org/glossary-terms.htm
http://www.iwmi.cgiar.org/pubs/PUB029/Report29.pdf

Fish Passage and Screening
http://www.usbr.gov/research/activity/1998-2000/er/1998/ER9803.htm
http://www.usbr.gov/research/activity/1998-2000/er/1998/ER9804.htm
http://www.usbr.gov/research/activity/1998-2000/er/1999/er9901.pdf
http://www.usbr.gov/research/activity/1998-2000/er/1999/er9905.pdf
http://www.usbr.gov/research/activity/1998-2000/abstracts/er00.01.pdf
http://www.usbr.gov/research/activity/1998-2000/abstracts/er00.06.pdf
http://www.usbr.gov/research/activity/1998-2000/abstracts/er00.07.pdf
http://www.id.nrcs.usda.gov/Engdwnld/standards/396.pdf
http://www.id.nrcs.usda.gov/Engdwnld/standards/410id-feb03.pdf
http://www.id.nrcs.usda.gov/Engdwnld/standards/320-id-may02.pdf
http://www.id.nrcs.usda.gov/Engdwnld/standards/449.pdf
http://www.dfw.state.or.us/ODFWhtml/InfoCntrFish/Management/FishPassage.html
http://www.oregoncoast.com/odfw/salmon_barriers.htm
http://www.stream.fs.fed.us/fishxing/biblio.html
http://www.chesapeakebay.net/fishpass.htm
http://www.4sos.org/wssupport/ws_rest/OregonRestGuide/
http://water.montana.edu/wildfish/manuals/Culvert%20Manual.pdf
http://www.wa.gov/wdfw/hab/engineer/mnl2000.pdf
http://www.fs.fed.us/r10/ref_reports/wfew/fish_blockage_at_culverts.pdf
http://www.dot.state.ak.us/stwddes/dcsenviron/assets/
pdf/procedures/dot_adfg_fishpass080301.pdf
http://www.wa.gov/wdfw/hab/engineer/habeng.htm
http://salmonidaho.com/screenshop/

River Restoration and Bank Stabilization
http://www.usbr.gov/research/activity/1998-2000/wr/1999/wr9929.pdf
http://www.usbr.gov/research/activity/1998-2000/abstracts/fi00.06.pdf
http://www.id.nrcs.usda.gov/Engdwnld/standards/395.pdf
http://www.id.nrcs.usda.gov/Engdwnld/standards/580id-feb03.pdf
http://www.id.nrcs.usda.gov/Engdwnld/engmainpage.html

Technical Note 12: Design of Stream Barbs
Technical Note 13: Design of Rock Weirs
Technical Note 15: Incorporation of Large Wood into Engineering Structures

http://www3.gov.ab.ca/env/water/reports/RiverChannelProcesses/Document1.pdf
http://www3.gov.ab.ca/env/water/reports/RiverChannelProcesses/Bed_and_Bank_Erosion.pdf
http://www3.gov.ab.ca/env/water/reports/RiverChannelProcesses/Ice_Processes.pdf
http://www3.gov.ab.ca/env/water/reports/RiverChannelProcesses/Streambank_Erosion.pdf
http://www.interfluve.com/pdf%20files/1996-2.pdf
http://water.montana.edu/wildfish/manuals/Placing%20Large%20Wood%20in%20Streams%20Guide.pdf
http://water.montana.edu/wildfish/manuals/WA_DOT_SalmonPassage.pdf
http://water.montana.edu/wildfish/manuals/WA_DOT_streambeds.pdf
http://swr.ucsd.edu/hcd/NMFSSCG.PDF
ftp://ftp.or.nrcs.usda.gov/pub/fotg/FOTG-Oregon/Section-4/Standards/410std.doc
http://www.interfluve.com/pdf%20files/sicncs.pdf
http://www.interfluve.com/pdf%20files/River-1998.pdf
http://www.interfluve.com/pdf%20files/AWRA-1999.pdf
http://www.interfluve.com/pdf%20files/ieca1998.pdf
http://www.interfluve.com/pdf%20files/meander_final.pdf
http://www.interfluve.com/pdf%20files/skidmore_2001_ncd.pdf
http://www.wa.gov/wdfw/hab/engineer/flowdsgn.htm
http://www.wa.gov/wdfw/hab/ahg/fishguid.pdf
http://www.wcc.nrcs.usda.gov/wtec/wtec.html
http://www.engr.utk.edu/hydraulics/openchannels/cover.htm

Habitat
http://www.usbr.gov/research/activity/1998-2000/abstracts/wr00.13.pdf
http://www.usbr.gov/research/activity/1998-2000/abstracts/er00.05.pdf
http://www.usbr.gov/research/activity/1998-2000/2000/wr9931.htm
http://www.usbr.gov/research/activity/1998-2000/2000/wr0014.htm
http://www.usbr.gov/research/activity/1998-2000/2000/er0004.htm
http://www.oweb.state.or.us/publications/habguide99.shtml
http://water.montana.edu/wildfish/manuals/California%20Restoration%20Manual.pdf
http://water.montana.edu/wildfish/manuals/NMFS_salmrest.pdf
ftp://ftp.or.nrcs.usda.gov/pub/fotg/FOTG-Oregon/Section-4/Standards/533std.doc
ftp://ftp.or.nrcs.usda.gov/pub/fotg/FOTG-Oregon/Section-4/Standards/587std.doc
http://www.epa.gov/owow/wetlands/restore/update/

Structural
http://www.usbr.gov/research/activity/1998-2000/2000/fi0002.htm
http://www.id.nrcs.usda.gov/Engdwnld/standards/587id-feb03.pdf
http://www.get-a-
quote.net/QuoteEngine/costbook.asp?WCI=CostFrameSet&BookId=1&PageNo=Y
http://www.armtec.ca/water/overshot.htm
http://www.interfluve.com/pdf%20files/degradation.pdf

Infiltration gallery
http://www.cs.fit.edu/~dclay/art7/TofC.htm
http://www.screenservices.com/Infiltration_Gallery.htm
http://www.cbfwa.org/files/province/cascade/projects/29025resp.pdf
http://pacific.fws.gov/jobs/orojitw/proj-info/josephine/summary/26-9502.htm
ftp://or.nrcs.usda.gov/pub/eng/SpecPract/

Software
http://www.id.nrcs.usda.gov/Engdwnld/engdownload.html
http://www.id.nrcs.usda.gov/Engdwnld/spreadsheets.html

Irrigation Standards and Checklists
http://www.cati.csufresno.edu/cit/rese/89/890803/
http://www.dfid-kar-water.net/w5outputs/electronic_outputs/small_scale_irrigation_checklist.pdf

Example Projects
http://www.verde.org/divert/homepg.html
http://www.pn.usbr.gov/news/03new/lemhi.html
http://www.pn.usbr.gov/news/03new/lemhipix.html
http://gallatincd.mt.nacdnet.org/concretediv.html
http://www.usbr.gov/wquality/wqhome/Conference/Papers/JH.html
http://www.r7.fws.gov/fish/outreach/pdf/fish_passage_restoration_in_alaska_poster.pdf

APPENDIX 2
Photographs of Constructed Diversion Projects

Photo 1. Push-up Gravel Dike

Photo 2. Lay-Flat Stanchions

Photo 3. Permanent Stop-Log Structure

Photo 4a. Permanent Barrier Rock Weir

Photo 4b. Permanent Barrier – Concrete Weir

Photo 5. Air Bladder

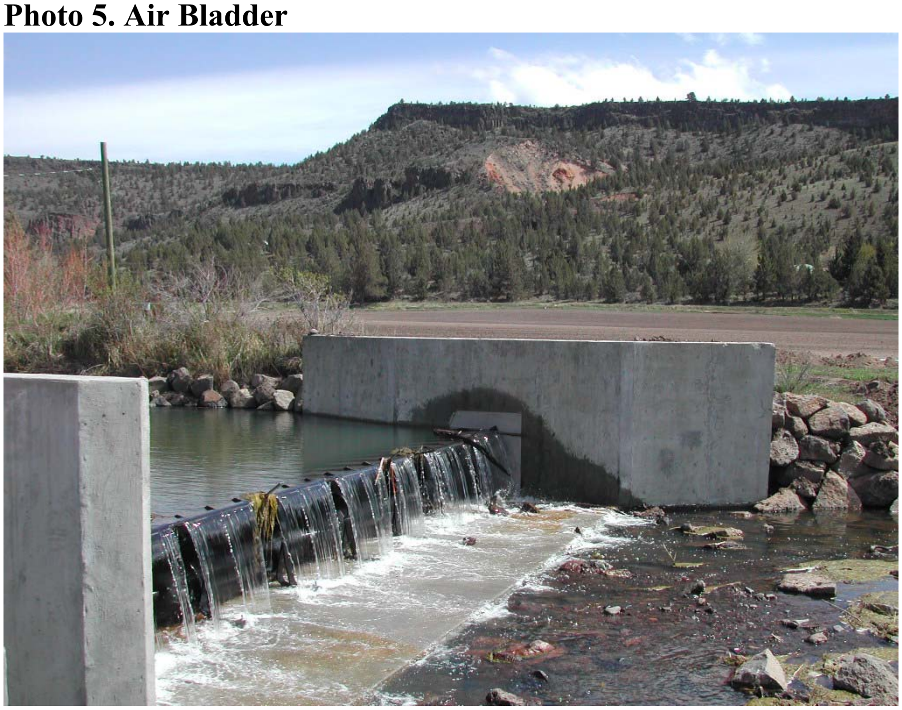


Photo 6. Vortex Tube

Photo 7. Screened Pump Intake

APPENDIX 3
Glossary of Irrigation Terms, by The Irrigation Association

http://www.irrigation.org/glossary-terms.htm